MRI of LV Global and Regional Function

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Introduction

As heart disease is the leading cause of death and disability in the Western World, assessment of cardiac function is of obvious clinical importance. In particular, the ejection fraction (EF), a measure of global cardiac function, has been shown to have prognostic significance, and is widely used as an index of the adequacy of cardiac mechanical function. However, conventional noninvasive methods of assessing cardiac function have many limitations. These include poor resolution, poor spatial registration between different images, limited sampling of locations in the heart wall, inability to account for motion of the heart through the imaging plane, and inability to track non-radial components of motion or motions within the heart wall. MRI provides the potential to overcome all these limitations.

A limitation of all cardiac function studies is their sensitivity to physiological effects, which will produce inherent variability of the results due to normal variability of the physiologic state. On the other hand, if the studies can be done quickly enough, we can potentially use various physiologic stresses to asses the functional reserve of the heart.

Global Cardiac Function

The good spatial registration and cardiac cycle synchronization of the images acquired with MRI allows us to calculate the volume of the ventricle at different phases of the cardiac cycle. This allows us to calculate various standard measures of global cardiac function, including the end-diastolic and end–systolic volumes (EDV, ESV); their difference, the stroke volume (SV); and the ratio of SV to EDV, the ejection fraction (EF). The cardiac output (CO) is then given by the product of SV and heart rate. If there is a left-to-right or right-to-left shunt, or a single incompetent valve, we may be able to calculate the corresponding shunt or regurgitant fraction from the difference between the SV of the right and left ventricles.

In calculating global function measures from cardiac MRI, we can use either bright or dark blood images, as long as the endocardial-blood interface is well defined. Following the echocardiography convention, we generally include the papillary muscles in the cavity, although a case can be made to include them with the wall. Similarly, there is some ambiguity as to how to handle the trabeculae lining the endocardium, which are more readily identified at end diastole than end systole. It seems most reproducible to

include everything between the mitral valve and the aortic valve as being in the ventricle, although not everyone agrees. The apex and base can be somewhat hard to define on short axis images; there may also be significant motion of the atrioventricular valve plane, moving the slice location of the base in the image set during the cycle. These structures may be better seen on long-axis images, although the formulas for volume calculations are a little more complicated. Contour extraction, which is necessary for all these calculations, is tedious, due to the frequent need for interactive guidance even with "automated" contour extraction, and prone to inconsistency. Attempts to automate the process have had only moderate success due to variability of anatomy and image quality.

Regional Cardiac Function

Dynamic display of a loop of cardiac cycle images permits qualitative assessment of regional cardiac wall motion, as in echocardiography, by following the endocardial surface with the "texture" of the endocardial trabeculae. Conventional measures of the serial positions of the endocardial surface can be used to calculate local radial components of the wall motion. However, the motion of this boundary can be significantly affected by the shared motion of other parts of the heart, as well as by the through-plane components of the motion of the curved heart wall through the fixed imaging slice location. Similarly, we can measure the local thickening of the heart wall. While this is less affected by adjacent wall motions, it is still subject to effects of through-plane motion. In either case, we must still extract the locations of the wall contours from the images to quantify the regional function; this is subject to the same limitations as the process of contour extraction in global function calculations. In addition, with conventional MRI, we cannot assess any components of the motion other than radial, and we cannot assess the distribution of motion within the wall.

Imaging with magnetization tagging of the tissue provides a means to assess the within-wall motion and potentially recover the full 3D motion of the heart wall. In tagging, a method such as spatial modulation of magnetization (SPAMM) is used to produce a pattern of altered magnetization within the myocardium; this can be done rapidly and safely, and results in a corresponding pattern of dark marks within the myocardium that move with the underlying tissue in subsequent images. While the tags fade over the cardiac cycle, this can be minimized with appropriate choices of imaging techniques. To measure the regional motion, we now can extract not only the contours, as with global function, but also the positions of the tags within the wall. At this point, this process is currently the limiting factor in clinical application of this approach to regional function, although there is good progress in overcoming this difficulty. Having extracted the serial tag positions, we can calculate the pattern of displacements within the wall and, from this, the corresponding pattern of regional deformation, or "strain". The strain is a tensor quantity, which can be computed either as components in local cardiac-based coordinates (including both strains and shears) or as reference frame-independent principal strains.

Imaging of motion-induced phase shifts provides an alternative method to assess within-wall components of motion. Short baseline phase measurements can be used to follow effective tissue velocities, while longer baseline measurements (with stimulated echo

imaging) can be used to follow interval displacements of the tissue. In either case, we need to have additional reference images to correct for any other possible sources of phase shifts. The analysis that can be done with such phase-shift derived velocity data includes integration of the velocities to find the net displacement; this may be subject to cumulative noise effects.